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# Modeling Laser-Plasma Interactions in MagLIF Experiment on NIF

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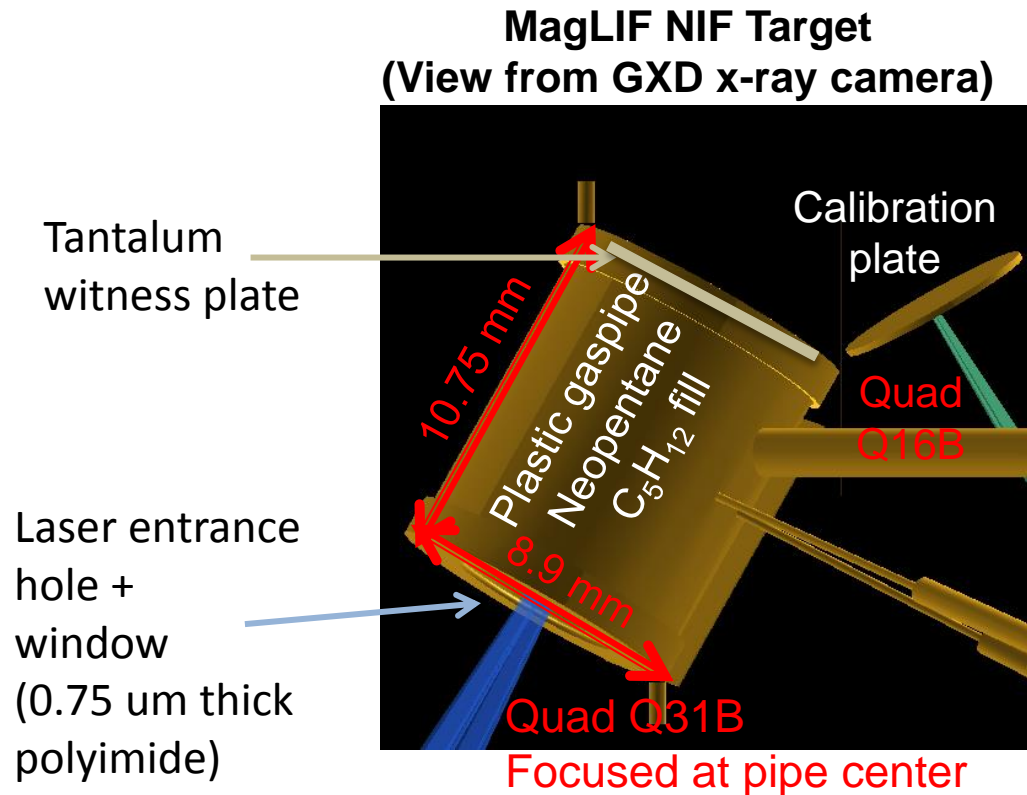# Modeling Laser-Plasma Interactions in MagLIF Experiment on NIF

Anomalous Absorption Meeting

D. J. Strozzi, R. L. Berger, A. B. Sefkow, S. H. Langer, T. Chapman, B. Pollock, C. Goyon, J. Moody

5 May 2016

Lawrence Livermore National Laboratory

# MagLIF shot on NIF gave excellent laser propagation and good agreement with modeling

**MagLIF NIF Target**
**(View from GXD x-ray camera)**



Tantalum witness plate

Calibration plate

10.75 mm

Plastic gaspipe
Neopentane
$C_5H_{12}$ fill

8.9 mm

Quad Q16B

Laser entrance hole + window (0.75 um thick polyimide)

Quad Q31B
Focused at pipe center

This talk:
shot N160128
Repeat, better diagnostics:
N160425

B. Pollock, R2-1:
Prior talk
More on expts

**Successfully demonstrated laser propagation at MagLIF fusion-gain scale**

National Nuclear Security Administration

# Summary: MagLIF NIF shots modeled with rad-hydro and LPI codes

**Modeling tools**

- HYDRA: ICF radiation-hydrodynamic code
  - Agrees with laser propagation down tube
  - Provides plasma conditions for LPI modeling
- Gain spectrum: linear gain exponents integrated along laser rays
  - 1D, linear, kinetic, fast – no speckles, filamentation, nonlinear kinetics
- pF3D: paraxial envelope propagation code
  - Massively parallel, 3D NIF-relevant volumes [R. Berger, S. Langer - Tuesday]

**SRS: peak reflectivity ~ 0.3%, from fill gas**

- Measured and gain spectra: close, contain two distinct wavelengths
- pF3D: two SRS wavelength groups: dominant one agrees with data

**SBS: Peak reflectivity ~ 3% when laser hits Ta plate**

- Gain spectrum close to data, but gain from gas not Ta
- pF3D modeling ongoing

# MagLIF NIF shot follows standard NIF "warm" (293 K) surrogacy approach

## NIF TARGET

- Gaspipe: 1 cm long, 1 cm diameter
- **Thin window:** 0.75 um polyimide
  - Use same warm and cryo
- MagLIF $D_2$ fill breaks window @ STP
- Use large hydrocarbon: match $n_e$
- Fill: neopentane $C_5H_{12}$ @ 1 atm.
  - $n_e = 0.116\ n_{crit}$ fully ionized
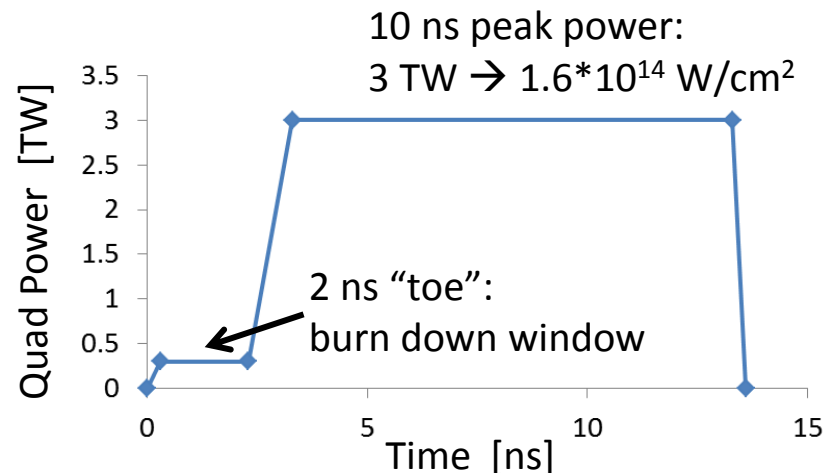  - Same $n_e$ as $D_2$ at 3.5 mg/cm$^3$
- No imposed B field: 10-20 T in 2017?

### $n_e / n_{crit}$ @ 8.5 ns [HYDRA sim.]
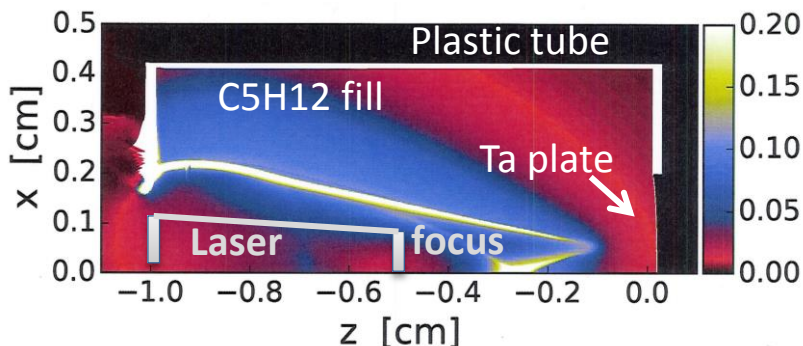


## NIF LASER: well-conditioned

- Wavelength: 351 nm "$3\omega$"
- One 30$^o$ cone quad (4 beams) – Q31B
- Nominal phase plates, F=8 for quad
- "Checkerboard" polarization smoothing
- SSD: 45 GHz
- Focal spot: ellipse, radii (824, 590) um

### Laser pulse

10 ns peak power:
3 TW → $1.6 \times 10^{14}$ W/cm$^2$



2 ns "toe": burn down window

# Low power and intensity gave low backscatter, some SBS when laser hits Tantalum plate

**Backscatter into FABS detector = lens aperture**



Laser hits Ta plate

SBS
SRS

Laser power [a.u.]

Peak SRS: 8.5 ns time of pF3D sims
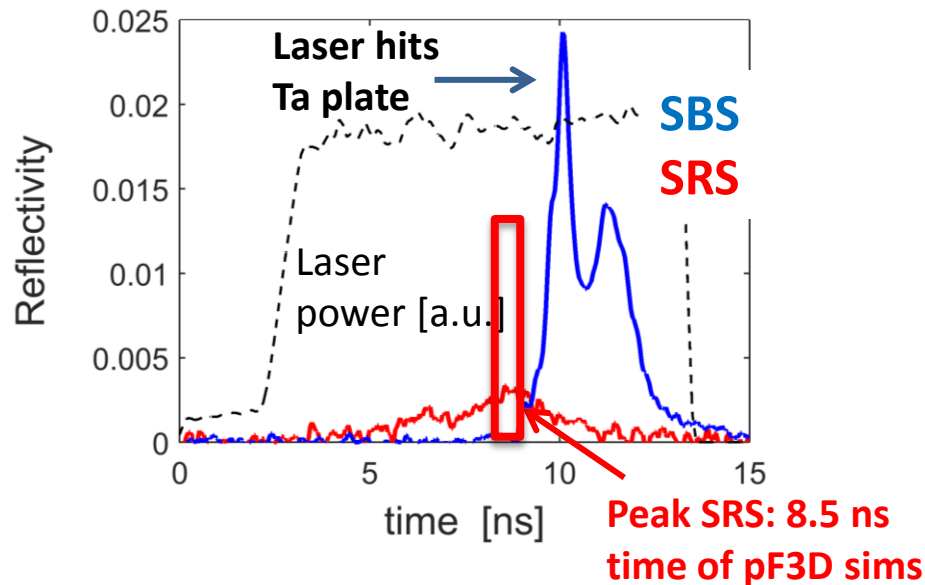
**SRS NBI (Near Backscatter Imager) Image centered on laser ports**



Quad Q31B

FABS detector in each laser beam port

"checkerboard" polarization smoothing
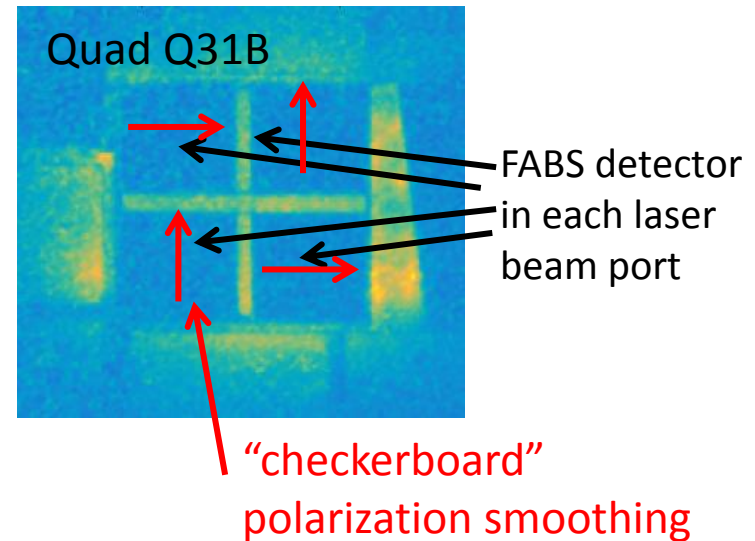
- Laser hits Ta plate at 10 ns – close to x-ray camera data
- Additional backscatter on NBI plate outside of lens ~ few *FABS: analysis ongoing

# SRS data and gain spectrum qualitatively similar before 10 ns
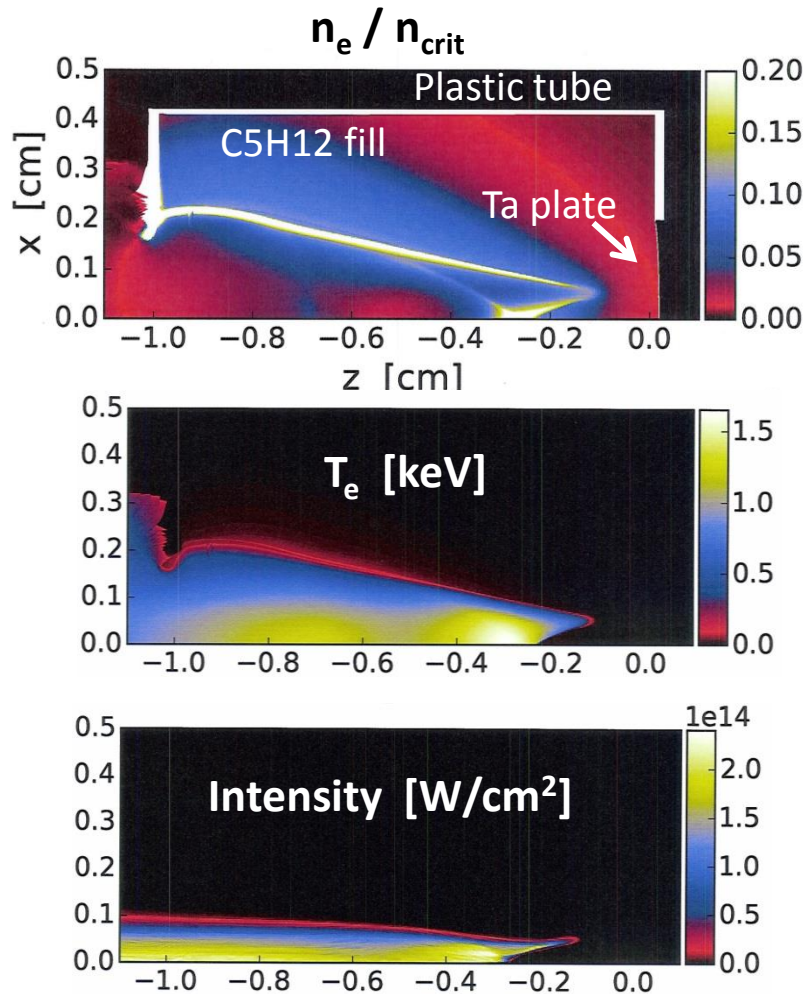
**Measured SRS spectrum [decibels]**
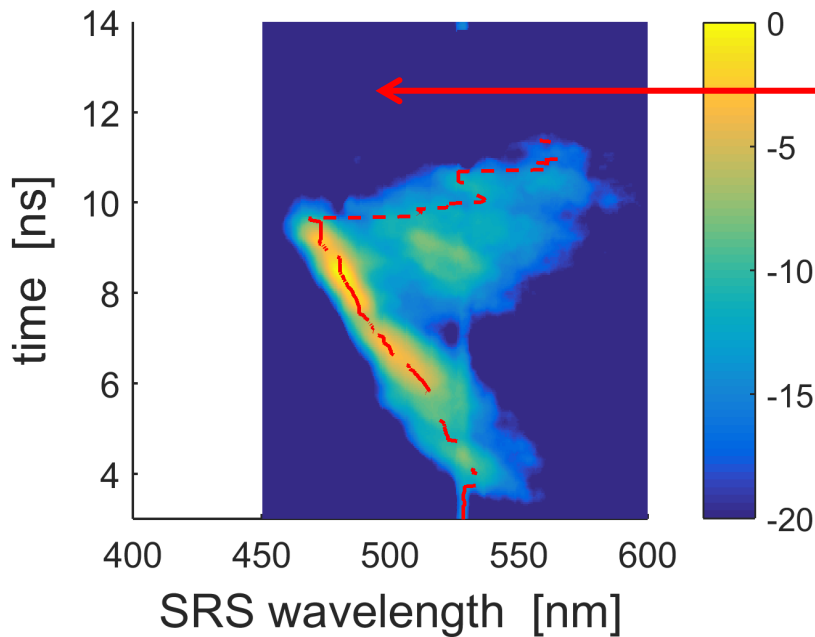
**SRS linear gain spectrum**
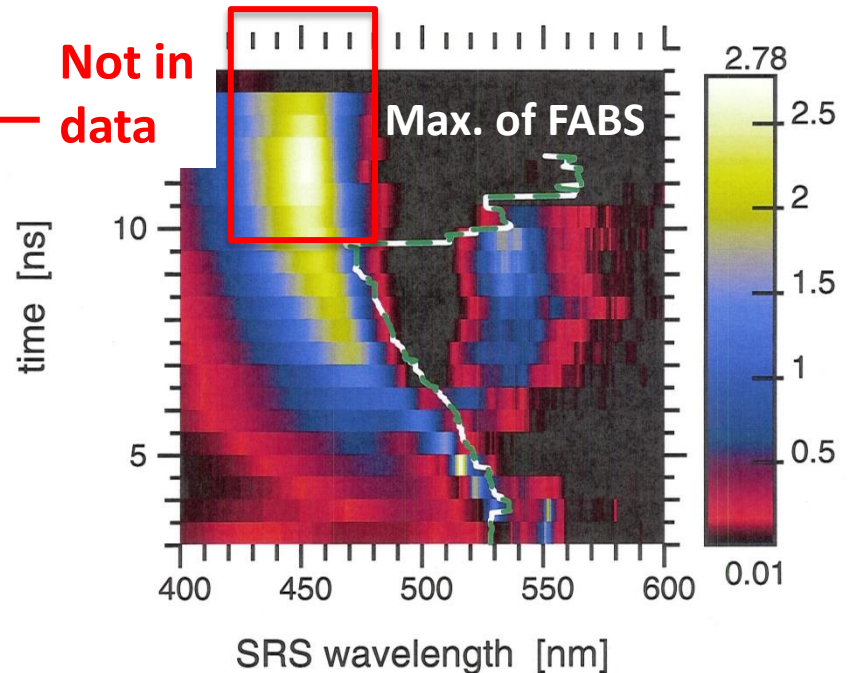


- Main feature moves to shorter wavelength with time → lower $n_e$
- Longer wavelength feature appears late in time

# Plasma conditions from HYDRA run at 8.5 ns: peak measured SRS



$n_e / n_{crit}$

Plastic tube

C5H12 fill

Ta plate

x [cm]

z [cm]

$T_e$ [keV]

Intensity [W/cm$^2$]

**HYDRA run:**

- No MHD
- f=0.05 electron heat flux limit
- DCA non-LTE atomic physics

# SRS at 8.5 ns: two features in data and gain spectrum

**Gain**

**FABS data**

pF3D wavelengths

SRS gain or FABS a.u.

SRS wavelength [nm]
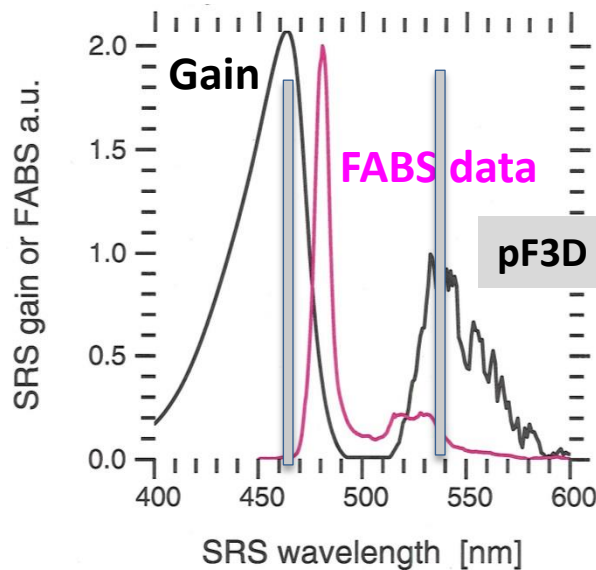
**SRS matching**

| $\lambda_{SRS}$ [nm] | Te [keV] | $n_e/n_{crit}$ | $k_{EPW}\lambda_{De}$ |
|---|---|---|---|
| 464 | 1 | 3.6% | 0.40 |
| 536 | 0.5 | 11.2% | 0.14 |

$T_e$ chosen from pF3D results

# pF3D[*]: paraxial envelope light propagation code, massively parallel

[*]R. L. Berger, C. H. Still, E. A. Williams, A. B. Langdon, *Phys. Plasmas* 1998

Light wave vector potential:

$$\vec{A}_0(\vec{x}, t) = \frac{1}{2}\tilde{A}_0(\vec{x}, t)\hat{p}\exp i(-\omega_0 t + \phi_0) + cc$$

Slowly-varying envelope

Polarization: fixed, in xy plane

Envelopes evolved:
- Laser light
- SRS light – 1 or 2 wavelength groups
- SRS Langmuir wave – 1 or 2 groups
- SBS light
- SBS ion wave:  no time enveloping

Background hydro w/ ponderomotive force:
- Filamentation
- Cross-beam energy transfer

Laser envelope equation:

$$\left[\partial_t + v_{g0}\partial_z - i\frac{(c^2/\omega_0)\nabla_\perp^2}{1 + \left(1 + k_0^{-2}\nabla_\perp^2\right)^{1/2}} + \nu_0 + i\partial_t\phi_0 + \frac{1}{2}\partial_z v_{g0}\right]\tilde{A}_0 \propto \delta n_{ef}\tilde{A}_0 + \frac{1}{2}\delta n_a\tilde{A}_B + \frac{1}{2}\delta n_l\tilde{A}_R$$
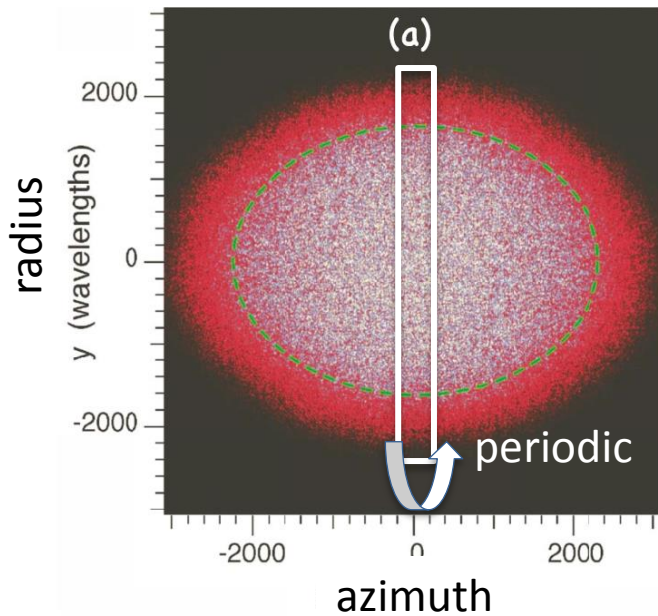
Advection: **not** strong damping limit

Diffraction: Feit-Fleck form

Damping

DAW phase shift

Refraction

SBS

SRS

# pF3D "Letterbox" run for backscatter: routine vs. "heroic" 3D run

## "Letterbox": slice in one transverse direction

- Same intensity distribution and speckle statistics as full beam
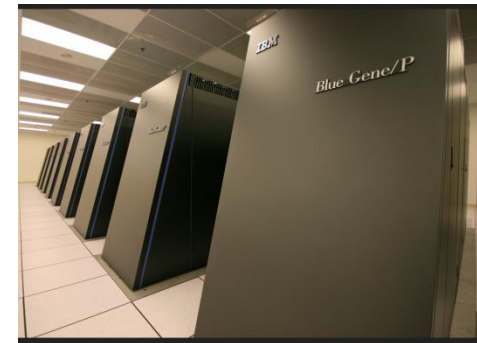
**Laser Intensity in transverse plane**



Sample letterbox: D. Hinkel et al., *Phys. Plasmas* 2008

## Computing resources

Spatial zoning: dx = dy = 2 $\lambda_0$,  dz = 3 $\lambda_0$

Plasma volume 1.9 mm$^3$

Zones: 3.9 billion

LLNL Sequoia machine: 8192 cpu's , ~ 1 day

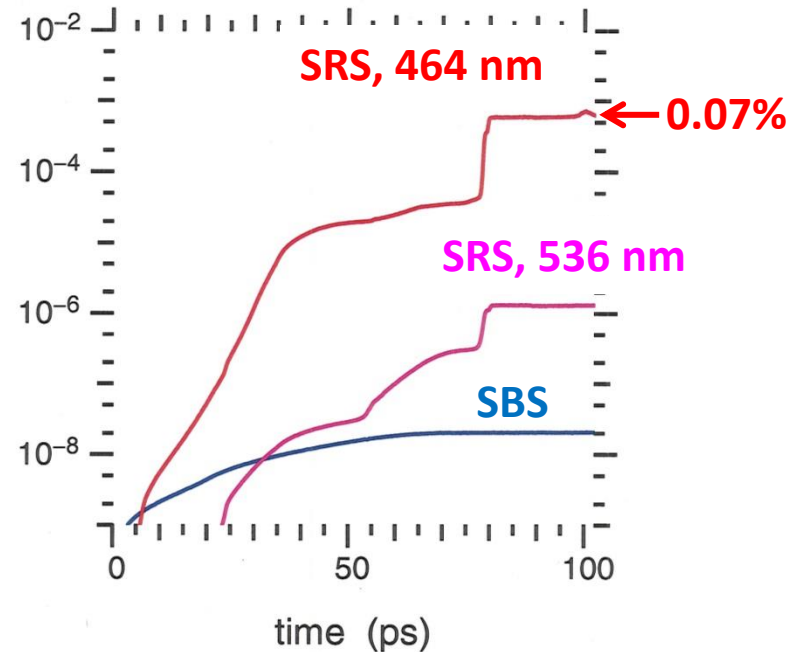# Peak SRS (8.5 ns): pF3D agrees with data: shorter wavelength SRS dominates, SBS small



$n_e / n_{crit}$

Plastic tube
C5H12 fill
Ta plate
pF3D domain



Gain
FABS data

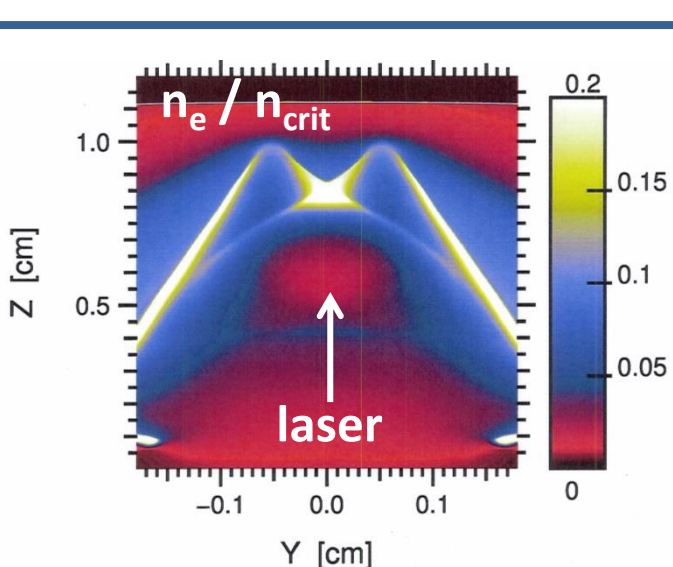pF3D wavelengths: 464, 536 nm
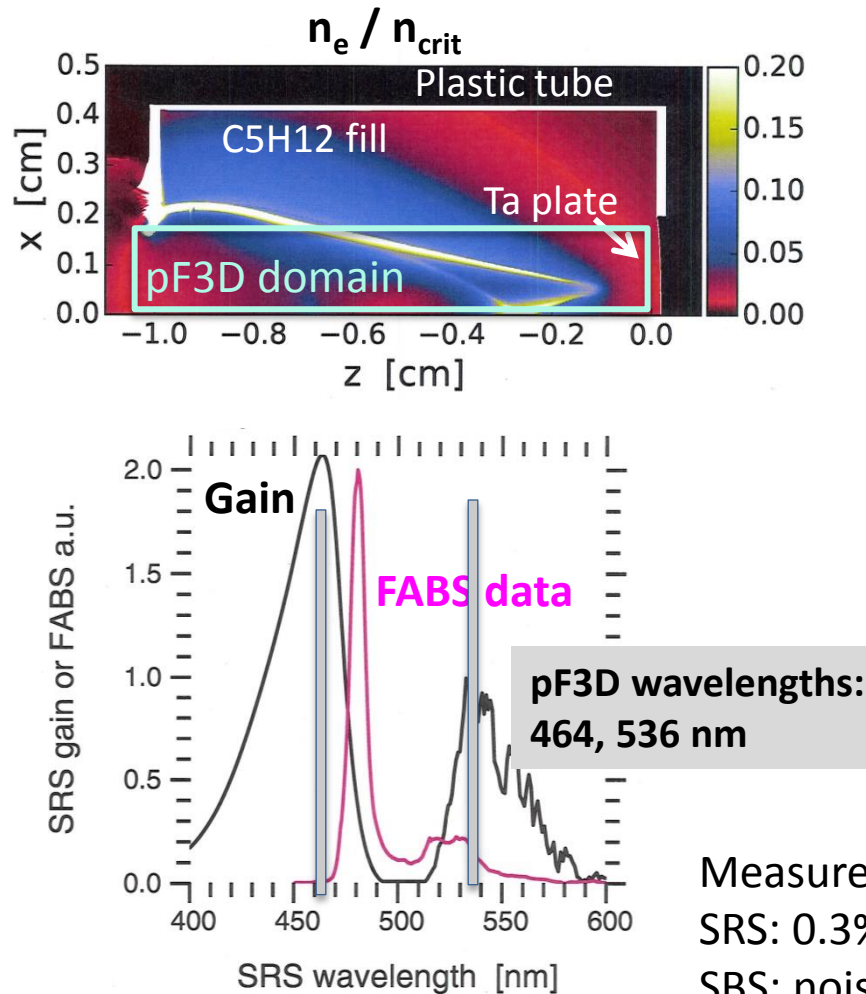
**Reflectivity: 2 SRS groups, and SBS**
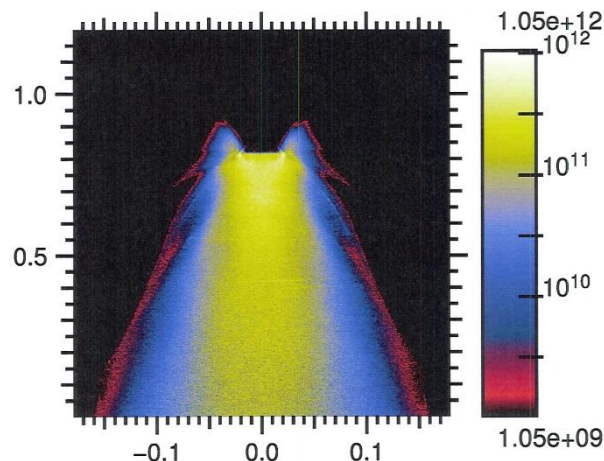


SRS, 464 nm
← 0.07%
SRS, 536 nm
SBS

Measured reflectivity into FABS:
SRS: 0.3%, at 480 nm, << at 540 nm
SBS: noise

# Peak SRS: SRS develops at end of laser path

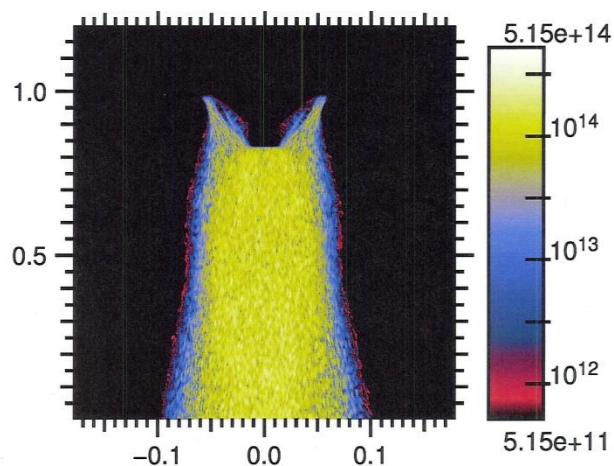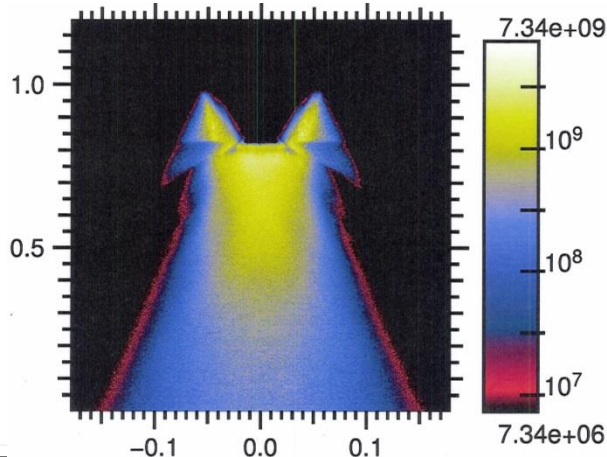SRS @ 464 nm intensity [W/cm²]

pF3D

- Time 104 ps
- Intensities on different log scales
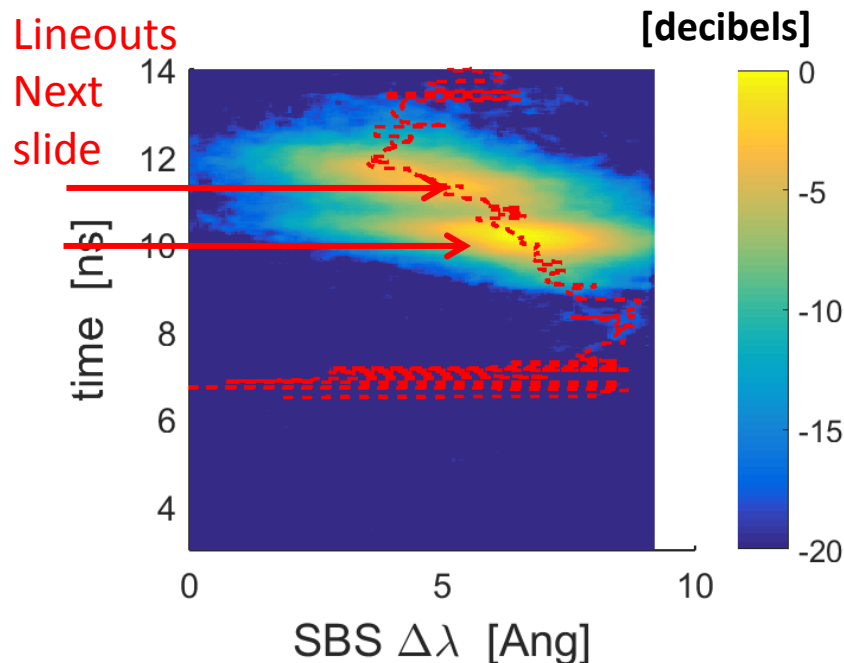- Aspect ratio not unity

Laser intensity [W/cm²]

SRS @ 536 nm intensity [W/cm²]

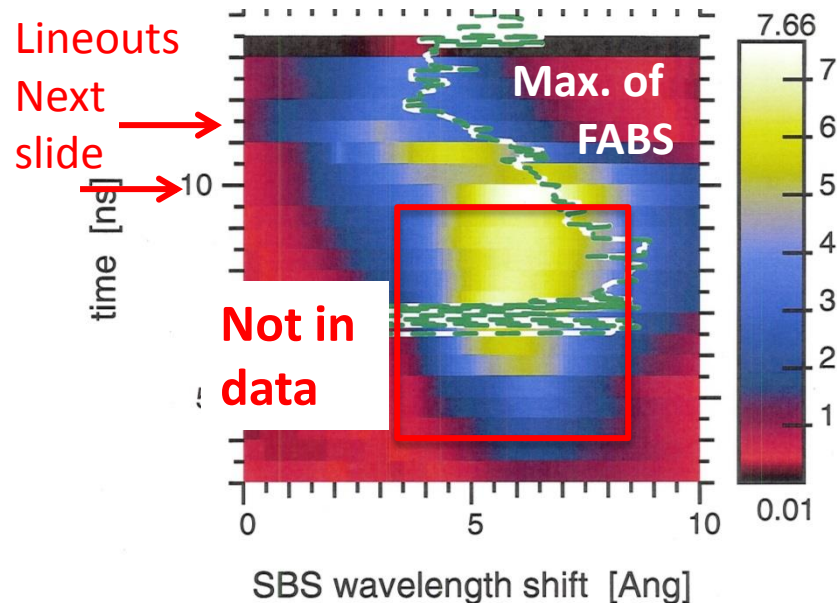# Late-time SBS gain spectrum consistent with data
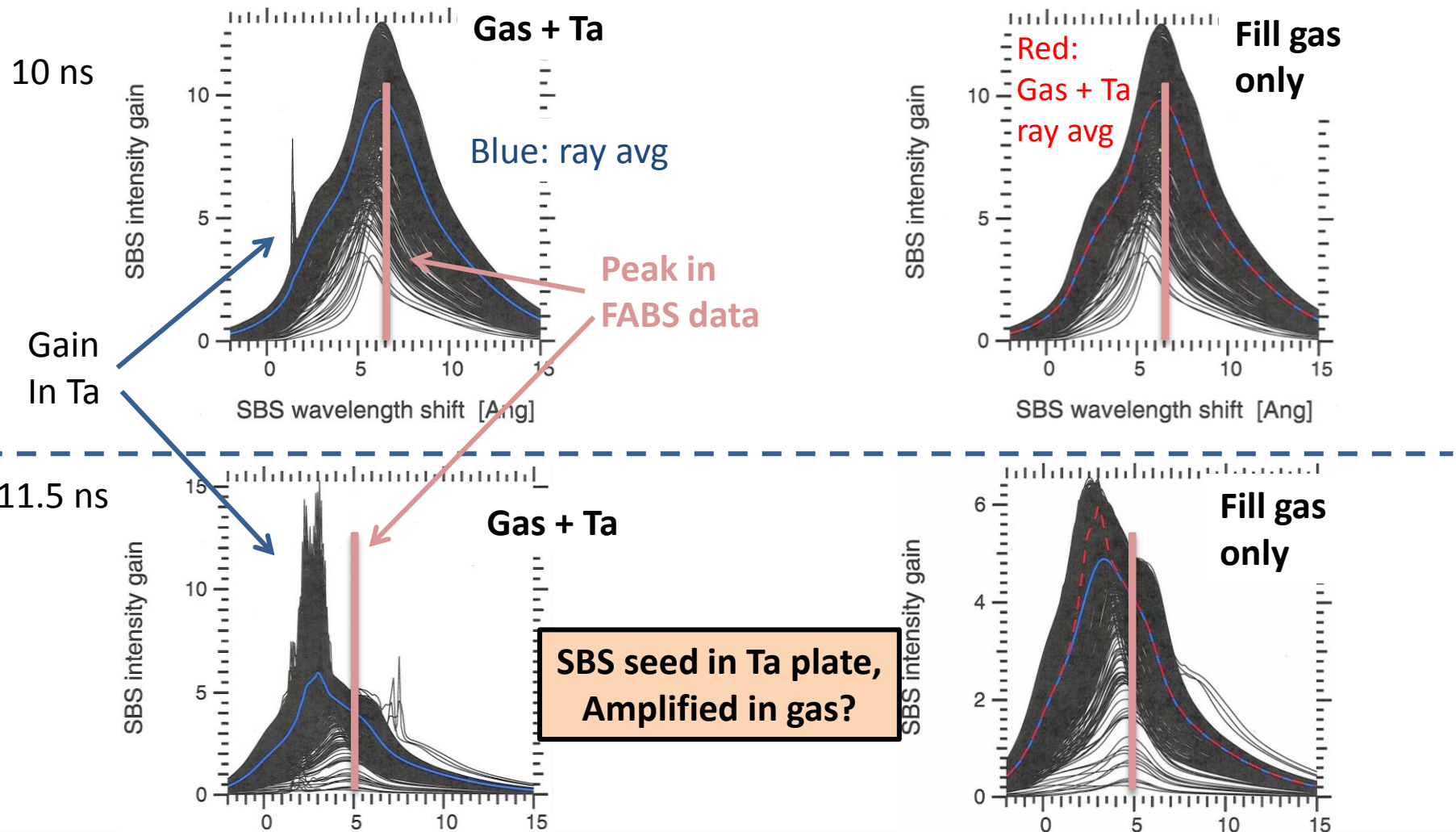
**Measured SBS spectrum**

**SBS linear gain spectrum close to data**



**Late-time SBS occurs when laser hits tantalum back plate: but where is it coming from?**

# SBS gain spectra late in time: most gain coming from gas, some at short wavelength from Ta



10 ns

**Gas + Ta**

Blue: ray avg

**Peak in FABS data**

Gain In Ta

**Red: Gas + Ta ray avg**

**Fill gas only**

11.5 ns

**Gas + Ta**

**SBS seed in Ta plate, Amplified in gas?**

**Fill gas only**

# Conclusions and future work

**Modeling**

- HYDRA correctly gives laser propagation, based on x-ray camera data
- SRS: two wavelengths in gain and data, pF3D gives same dominant one as data
- SBS burst when laser hitting Ta back plate, but gain in gas at that time

**Future NIF shots**

- Push to higher backscatter risk:
  - Higher intensity
  - Higher fill density
- Cryogenic $D_2$ fill, thin window: ignition relevant, instead of warm surrogate $C_5H_{12}$
- Imposed B field: 10-20 T in 2017?

B. Pollock, R2-1:
Prior talk
More on expts

**Warm C5H12 fill, no imposed B field:**
**Successful laser propagation at MagLIF fusion-gain scale**

**Cryogenic D2 fill, imposed B field:**
**Will test complete MagLIF scheme – to be done soon…**

# BACKUP BELOW

**SBS shift in high *Z* plasma:**

$$\delta\lambda[\text{Å}] \approx 7.3 \left( \frac{Z}{A} T_e[keV] \right)^{1/2} \left( 1 + \frac{\vec{u} \cdot \vec{k}_0}{c_{ac}} \right) \implies 4.9\text{Å}$$

Tantalum: A=181, Z=42
$T_e$ = 2 keV, u=0

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